AMENDMENTS TO THE SPECIFICATION

Please replace Paragraphs [0002], [0005], [0006], [0007], [0008], [0009], [0010], [0011], [0012], [0013], [0014], [0016], [0017], [0019], [0022], [0023], [0024], [0025], [0026], [0027], [0028], [0030], [0031], [0032], [0033], [0036], [0037], [0038], [0039], [0040], [0045], [0046], [0048], [0049], [0050], [0051], [0052], [0054], [0055], [0056], [0057,], [0058], [0059], [0060], [0061], [0068], [0071], [0076], [0081], [0082], [0083], [0084], [0085], [0087], [0088], [0091], [0092], [0093], [0096], [0097], [0099], [0101], [0103], [0106], [0107], [0108], [0110] and [0111], with the following paragraphs rewritten in amendment format:

SYSTEMS AND METHODS FOR DETERMINING INCONSISTENCY ~~DEFECT~~ CHARACTERISTICS OF A COMPOSITE STRUCTURE

FIELD

[0002] The present disclosure ~~invention~~ relates generally to the fabrication of composite structures with material placement machines, and more particularly (but not exclusively) to systems and methods for determining inconsistency ~~defect~~ characteristics of a composite structure, such as inconsistency ~~defect~~ density-per-unit area and/or cumulative inconsistency ~~defect~~ width-per-unit area.

BACKGROUND

[0005] Unfortunately, inconsistencies ~~defects~~ can occur during the placement of the composite strips onto the underlying composite structure. Such inconsistencies ~~defects~~ can include tow gaps, overlaps, dropped tows, puckers (i.e., raised regions in a tow), and twists. In addition, there are foreign objects and debris (FOD), such as resin balls and fuzz balls, that can accumulate on a surface of the composite structure which must be detected, identified and eventually removed from the ply surface.

[0006] Composite structures fabricated by automated material placement methods typically have specific maximum allowable size requirements for each inconsistency ~~flaw~~, with these requirements being established by the production program. Production programs also typically set well-defined accept/reject criteria for maximum allowable number of (i.e., density) of inconsistencies ~~defects~~ per-unit area and maximum allowable cumulative inconsistency ~~defect~~ width-per-unit area.

[0007] To ensure that the composite laminates fabricated by fiber placement processes satisfy the requirements pertaining to inconsistency ~~defect~~ size, the structures are typically subjected to a 100% ply-by-ply visual inspection. These inspections are traditionally performed manually during which time the fiber placement machine is stopped and the process of laying materials halted until the inspection and subsequent action to address the inconsistencies ~~repairs~~, if any, are completed. In the meantime, the fabrication process has been disadvantageously slowed by the manual inspection process and machine downtime associated therewith.

[0008] Recently, systems have been developed that are capable of detecting, measuring, and marking individual inconsistencies ~~defects~~ in the composite structure. Exemplary systems and methods capable of accurately and reliably detecting, measuring and/or marking inconsistencies ~~defects~~ in a composite structure are disclosed in U.S. Patent Application No. 09/819,922, filed March 28, 2001, ~~entitled "System and Method for Identifying Defects in a Composite Structure";~~ U.S. Patent Application No. 10/217,805, filed August 13, 2002~~, entitled "System for Identifying Defects in a Composite Structure";~~ and U.S. Patent Application No. 10/628,691, filed July 28, 2003[[.]]~~, entitled "Systems and Methods for Identifying Foreign Objects and Debris (FOD) and Defects During Fabrication of a Composite Structure."~~ The entire disclosures of U.S. Patent Application Nos. 09/819,922, 10/217,805, and 10/628,691 are each incorporated herein by reference as if fully set forth herein.

[0009] Although these inspection systems have worked well for their intended purposes, the inventors hereof have recognized that it would be even more

beneficial to provide systems and methods that are capable of determining [[a]]an inconsistency ~~defect~~ characteristic of a composite structure, such as the composite structure's inconsistency ~~defect~~ density-per-unit area and/or cumulative inconsistency ~~defect~~ width-per-unit area.

SUMMARY

[0010] Systems and methods for determining [[a]]an inconsistency ~~defect~~ characteristic of a composite structure, such as inconsistency ~~defect~~ density-per-unit area and/or cumulative inconsistency ~~defect~~ width-per-unit area. In one ~~preferred~~ embodiment, a method for determining ~~a~~ an inconsistency ~~defect~~ characteristic of a composite structure generally includes: determining a first distance from a first reference point of the composite structure to an inconsistency ~~defect~~; determining a second distance from a second reference point of the composite structure to the inconsistency ~~defect~~; using the first and second distances to establish a reference area of the composite structure; and considering each inconsistency ~~defect~~ detected within the reference area and producing therefrom ~~a~~ an inconsistency ~~defect~~ characteristic representative of the composite structure.

[0011] The features, functions, and advantages can be achieved independently in various embodiments of the present disclosures ~~inventions~~ or may be combined in yet other embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present disclosure ~~invention~~ will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0013] FIG. 1 is a schematic view of an exemplary composite structure illustrating linear and lateral distances to [[a]]an inconsistency ~~defect~~ in the composite structure according to one embodiment of the present disclosure ~~invention~~;

[0014] FIG. 2 is a perspective view of a compaction roller having a code ring coupled thereto for common rotation therewith and a photo sensor positioned to

monitor the code ring according to one embodiment of the present disclosure ~~invention~~;

[0016] FIG. 4 is a schematic view of a system according to one embodiment of the present disclosure ~~invention~~;

[0017] FIG. 5 is a perspective view of a system according to another embodiment of the present disclosure ~~invention~~;

[0019] FIG. 7 is a perspective view of a system according to another embodiment of the present disclosure ~~invention~~;

[0022] FIG. 10 is a view of a computer display and user controls according to one embodiment of the present disclosure ~~invention;~~

[0023] FIG. 11 is a view of an exemplary part model which may be imported from external or third party software according to one embodiment of the present disclosure ~~invention~~;

[0024] FIG. 12 is a view of the part model shown in FIG. 11 with a course grid overlay according to one embodiment of the present disclosure ~~invention~~;

[0025] FIG. 13 is a view of the part model shown in FIG. 12 but with the course grid overlay repositioned to represent a change in orientation for the new ply according to one embodiment of the present disclosure ~~invention~~;

[0026] FIG. 14 is a view of two computer displays simultaneously displaying the computer display shown in FIG. 10 and the part model and course grid overlay shown in FIG. 13 according to one embodiment of the present disclosure ~~invention~~;

[0027] FIG. 15 is a view of a computer display according to one embodiment of the present disclosure ~~invention~~; and

[0028] FIG. 16 is a view of a computer display according to one embodiment of the present disclosure ~~invention~~.

DETAILED DESCRIPTION ~~OF THE EXEMPLARY EMBODIMENTS~~

[0030] According to one aspect, the present disclosure ~~invention~~ provides a method for determining [[a]]an inconsistency ~~defect~~ characteristic of a composite structure, such as inconsistency ~~defect~~ density-per-unit area and/or cumulative inconsistency ~~defect~~ width-per-unit area. In one embodiment, the method generally includes: determining a first distance from a first reference point of the composite structure to [[a]]an inconsistency ~~defect~~; determining a second distance from a second reference point of the composite structure to the inconsistency ~~defect~~; using the first and second distances to establish a reference area of the composite structure; and considering each inconsistency ~~defect~~ detected within the reference area and producing therefrom [[a]]an inconsistency ~~defect~~ characteristic representative of the composite structure.

[0031] Various ~~Preferred~~ embodiments of the present disclosure ~~invention~~ provide methods for determining for a reference area or region of a composite structure one or more of the following inconsistency ~~defect~~ characteristics: a total inconsistency ~~defect~~ count, total inconsistency ~~defect~~ width, inconsistency ~~defect~~ density-per-unit area (i.e., number of inconsistencies ~~defects~~-per-unit area), cumulative inconsistency ~~defect~~ width-per-unit area and/or inconsistency ~~defect~~ location. Various embodiments allow these inconsistency ~~defect~~ characteristics to be determined as the composite structure is being fabricated, thereby eliminating the need for manual inspection processes and the machine downtime associated therewith.

[0032] In one embodiment, the method generally includes determining a linear distance to [[a]]an inconsistency ~~defect~~ along a course being laid by a material placement machine; determining a lateral distance to the inconsistency ~~defect~~ from a first end of the composite structure; using the linear and lateral distances to establish a reference area; totaling inconsistencies ~~defects~~ within the reference area; dividing the inconsistency ~~defect~~ total by the reference area to determine [[a]]an inconsistency ~~defect~~ density-per-unit area; determining a width for each inconsistency ~~defect~~ within the reference area; totaling the widths of the inconsistencies ~~defects~~ within the reference area; and dividing the width total by the reference area to determine a cumulative inconsistency ~~defect~~ width-per-unit area.

[0033] In an ~~the~~ exemplary embodiment, the method includes determining both inconsistency ~~defect~~ density-per-unit area and cumulative inconsistency ~~defect~~ width-per-unit area. Alternatively, other embodiments can include determining any one or combination of total inconsistency ~~defect~~ count, total inconsistency ~~defect~~ width, inconsistency ~~defect~~ density-per-unit area, cumulative inconsistency ~~defect~~ width-per-unit area and/or inconsistency ~~defect~~ locations. Further embodiments can include determining any one or combination of total inconsistency ~~defect~~ count, total inconsistency ~~defect~~ width, inconsistency ~~defect~~ density, cumulative inconsistency ~~defect~~ width and/or inconsistency ~~defect~~ locations for the entire composite structure in which case a reference area need not necessarily be established.

[0036] With further reference to FIG. 1, the sixth course 23 of the composite structure 22 includes [[a]]an inconsistency ~~defect~~ 36 in the form of a tow gap. Additionally, or alternatively, the composite structure 22 can also include other types of inconsistencies ~~defects~~ such as overlaps, dropped tows, puckers, twists, and foreign objects and debris (FOD) with such inconsistencies ~~defects~~ being counted and measured by embodiments of the present disclosure ~~invention~~.

[0037] The dashed line 19 represents the linear distance along the sixth course 23 to the inconsistency ~~defect~~ 36. The dashed line 21 represents the lateral distance to the inconsistency ~~defect~~ 36 from a first end 11 of the composite structure 22.

[0038] Various methods may be used to determine linear distances along a course to [[a]]an inconsistency ~~defect~~ detected in that course. In an exemplary embodiment, linear distance to [[a]]an inconsistency ~~defect~~ along a course can be determined by multiplying the linear velocity of the material placement head unit along the course with the amount of time that has lapsed between when the course began and when the inconsistency ~~defect~~ is detected.

[0039] When [[a]] an inconsistency ~~defect~~ is detected, a signal can be produced that not only indicates inconsistency ~~defect~~ detection but may also trigger measurement and marking of the inconsistency ~~defect~~. Exemplary systems and

methods capable of detecting inconsistencies~~ defects~~ in a composite structure are described generally below and in more detail in U.S. Patent Application No. 09/819,922, filed March 28, 2001, ~~entitled "System and Method for Identifying Defects in a Composite Structure";~~ U.S. Patent Application No. 10/217,805, filed August 13, 2002~~, entitled "System for Identifying Defects in a Composite Structure";~~ and U.S. Patent Application No. 10/628,691, filed July 28, 2003.~~, entitled "Systems and Methods for Identifying Foreign Objects and Debris (FOD) and Defects During Fabrication of a Composite Structure."~~ The entire disclosures of U.S. Patent Application Nos. 09/819,922, 10/217,805, and 10/628,691 are each incorporated herein by reference as if fully set forth herein.

[0040] The start and stop of a course can be determined using signals from the machine load cell which indicate whether or not pressure is being applied to the compaction roller 20 (FIGS. 2 and 5). Receipt of a "pressure on" signal from the machine load cell indicates that the compaction roller 20 is in contact with the composite structure 22 and therefore, that a course has been started. Receipt of a "pressure off" signal indicates that the compaction roller 20 is no longer in contact with the composite structure 22, and therefore that a course has been completed. Accordingly, the time between course start and inconsistency~~ defect~~ detection can be determined by tracking the amount of time elapsing between receipt of the "pressure on" signal from the machine load cell and the receipt of the signal indicating detection of [[a]]an inconsistency~~ defect~~.

[0045] In another exemplary embodiment, the linear distance to [[a]]an inconsistency~~ defect~~ along a course can be determined by counting the number (whole and fractional) of revolutions the compaction roller 20 makes from the start of the course to the inconsistency~~ defect~~ and multiplying that number of revolutions by the circumference of the compaction roller 20. By way of example, the photo sensor 7 and code ring 1 can be used to count the number of revolutions of the compaction roller 20 between receipt of the "pressure on" signal from the machine load cell and receipt of the signal indicating that [[a]]an inconsistency~~ defect~~ has been detected.

[0046] Various methods can also be employed to determine the lateral distances to inconsistencies~~ defects~~ from the first end 11 of the composite structure

22. See FIG. 1. In one exemplary embodiment, lateral distance to [[a]] an inconsistency ~~defect~~ can be calculated by counting the total number of completed courses, not including the course in which the inconsistency ~~defect~~ resides, and then multiplying the average width of a course by the number of completed courses. This method is particularly effective for tape placement in which each course is the same width, i.e., the width of the tape.

[0048] For fiber placement courses in which the width of each course may not be equal, the lateral distances to inconsistencies ~~defects~~ can be accurately determined by employing a "software ruler." More specifically, the lateral distance can be determined by acquiring a digital image of at least the portion of the composite structure including the lateral distance; selecting a pixel set from the digital image that represents the lateral distance; counting the number of pixels comprising the pixel set; and correlating the pixel count with correlation data (e.g., a predetermined relationship between pixel count and distance) to compute an indirect quantitative measurement for the lateral distance.

[0049] The width of [[a]]an inconsistency ~~defect~~ can be determined in a similar manner. After a digital image of the inconsistency ~~defect~~ has been acquired, a pixel set is selected from the digital image that represents the width of the inconsistency ~~defect~~. The pixels comprising the pixel set are counted, and the pixel count is then correlated with correlation data (e.g., a predetermined relationship between pixel count and distance) to compute an indirect quantitative measurement for the inconsistency ~~defect~~ width.

[0050] Alternatively, inconsistency ~~defect~~ width may be determined by multiplying the linear velocity of the head unit (as determined in a manner described above) by the amount of time required for the head unit to traverse the distance separating the opposed sides of the inconsistency ~~defect~~.

[0051] The reference area can be defined as any region of the composite structure which is currently under inspection for inconsistencies ~~defects~~ and which has a surface area about equal to the surface area of the reference area. Further, the reference area can be sized to include any suitable surface area, such as five square

inches, one square foot, etc. In addition, the reference area can be sized in accordance with production requirements to include only a portion of the composite structure. Alternatively, other embodiments can utilize a reference area corresponding in size to the entire composite structure.

[0052] The reference area can be established in various ways. In one exemplary embodiment, the reference area comprises any region of the composite structure that is bounded by the linear and lateral distances to the presently detected inconsistency ~~defect~~. For example, and referring to FIG. 1, a reference area can be established for the inconsistency ~~defect~~ 36 as the rectangular portion of the composite structure 22 defined by the dashed lines 19 and 21 and the composite structure's first end 11 and lower side edge.

[0054] In either of the aforementioned embodiments, the bounded reference areas can be tracked during the inspection, for example, in a lookup table. The lookout table might then be compared to a running tally of inconsistencies ~~defects~~ (e.g., running inconsistency ~~defect~~ quantity and/or running inconsistency ~~defect~~ width) during the inspection.

[0055] In yet other embodiments, the reference area is defined as the region of the composite structure which includes the preceding portion of the course in which the presently detected inconsistency ~~defect~~ resides and all of the completed, preceding courses. For example, and referring to FIG. 1, a reference area can be established for the inconsistency ~~defect~~ 36 as the first five courses to the left of course 23 and that portion of the sixth course 23 below the inconsistency ~~defect~~ 36.

[0056] In further embodiments, the reference area is defined as a region of the composite structure which includes the preceding portion of the course in which the presently detected inconsistency ~~defect~~ resides and a predetermined number of completed courses immediately preceding the course in which the presently detected inconsistency ~~defect~~ resides. For example, a reference area can be established for the inconsistency ~~defect~~ 36 as that portion of the sixth course 23 below the inconsistency ~~defect~~ 36 and the three courses (i.e., third, fourth and fifth courses) to the immediate left of the sixth course 23 in FIG. 1.

[0057] In certain embodiments, a comparison is made between the cumulative inconsistency ~~defect~~ width-per-unit area and a maximum allowable cumulative inconsistency ~~defect~~ width-per-unit area to determine whether a composite structure is acceptable or should be rejected. The maximum allowable cumulative inconsistency ~~defect~~ width-per-unit area can be set by production requirements. When the cumulative inconsistency ~~defect~~ width-per-unit area exceeds the maximum allowable cumulative inconsistency ~~defect~~ width-per-unit area, the manufacturing process can be halted and/or an indicator of unacceptability can be provided, for example, by a user interface 76 (FIG. 4) described below.

[0058] Additionally, or alternatively, certain embodiments include comparing the inconsistency ~~defect~~ density-per-unit area and a maximum allowable inconsistency ~~defect~~ density-per-unit area to determine whether a composite structure is acceptable or not. The maximum allowable inconsistency ~~defect~~ density-per-unit area can be set by the production requirements. When the inconsistency ~~defect~~ density-per-unit area exceeds the maximum allowable inconsistency ~~defect~~ density-per-unit area, the manufacturing process may be halted and/or an indicator of unacceptability may be provided, for example, via the user interface 76 (FIG. 4) described below.

[0059] An exemplary system 10 which can be used to detect inconsistencies ~~defects~~ in a composite structure is illustrated in FIG. 4. As shown in FIG. 4, the system 10 includes at least one camera 12 and at least one light source 14. The camera 12 is connected to a processor 66 for interpreting the images the camera 12 captures, or to a storage device 64 for storing the images, or both, as discussed more fully below.

[0060] The light source 14 is positioned to emit light for illuminating the composite structure 22. The illumination is reflected differently by inconsistencies ~~defects~~ in the composite structure than from portions of the composite structure that are inconsistency ~~defect~~ free. For example, illumination reflecting off non-inconsistent

~~non-defective~~ portions of the composite structure 22, and light that fails to reflect off of inconsistencies ~~defects~~ in the composite structure 22, or vice versa, creates visible images that can be captured by the camera 12. Details regarding systems and methods for identifying inconsistencies ~~defects~~ in a composite structure during fabrication thereof are included in previously referred to U.S. Patent Application Nos. 09/819,922, 10/217,805, and 10/628,691.

[0061] As shown in FIG. 4, the camera 12 is positioned near the composite structure 22 so as to capture images of portion of the composite structure being illuminated, which is typically immediately downstream of the nip point at which a composite tow is joined with the underlying structure. Alternatively, and as shown in FIG. 5, a reflective surface 16 may be positioned near the composite structure (the composite structure is not shown in FIG. 5), and angled such that the reflective surface 16 reflects an image of the illuminated portion of the composite structure. The camera 12 may be positioned to point toward the reflective surface 16 in order to capture close-range images of the illuminated portion of the composite structure from the reflective surface 16. More than one reflective surface 16 may also be utilized in further embodiments of the present disclosure ~~invention~~ in which the reflective surfaces 16 cooperate in order to direct images of the illuminated portion of the composite structure to the camera 12.

[0068] In FIG. 4, the light source 14 is shown positioned at an oblique angle 37 relative to the composite structure 22. The oblique angle 37 may be about forty-five degrees, although other angles are possible depending on the application. In addition, the light source 14 is also shown positioned to emit light in a direction substantially perpendicular to the direction of placement of the strips 24 in order to highlight the inconsistencies ~~defects~~ 36, as described below.

[0071] The quality and magnitude of the surface illumination of the composite structure is greatly affected by ambient lighting and by the reflectivity of the material. Accordingly, embodiments of the present disclosure ~~invention~~ advantageously employ an infrared light source to more effectively illuminate dark

inconsistencies ~~flaws~~ on a dark background. In this regard, the light source 14 can be selected from an infrared light or another type of light having an infrared component, such as a halogen light source (FIG. 6) or other incandescent light sources (not shown). In other embodiments, the light source 14 can also include a fluorescent light source (e.g., white light LEDs, low pressure/mercury filled phosphor glass tube, etc.), a strobe or stroboscopic light source, a noble gas arc lamp (e.g., xenon arc, etc.), metal arc lamp (e.g., metal halide, etc.) and a lasers (e.g., pulsed lasers, solid state laser diode arrays, infrared diode laser arrays, etc.). The light from the light source 14 may also be pumped from through optical fibers to the point of delivery, such as is shown in FIG. 7.

[0076] Referring back to FIG. 5, the system 10 may further include a light reflection element 18 located near the light source 14. The reflection element 18 include a series of light reflecting surfaces 40 (FIG. 6) that redirect the light towards the desired area to be illuminated. This levels the illumination across the surface and eliminates, or at least substantially reduce, areas of intense light (i.e., hotspots) created by the brightest portion of the light source 14. Hotspots are undesirable because hotspots prevent consistent illumination of the composite structure, which may lead to inconsistencies ~~errors~~ during the processing of the images captured by the camera 12.

[0081] It has been observed that the composite structure 22 produces high glare when illuminated across the direction of placement of the strips 24 but produces substantially less glare when illuminated along the direction of placement of the strips 24. The systems and methods of at least some embodiments exploit the high-glare/low-glare phenomenon by casting light across the top layer of the composite strips 24 in a direction substantially perpendicular to the direction of placement of the strips 24. This produces a relatively large amount of glare on the top layer of the composite structure 22. The underlying layers, which produce significantly less glare than the top layer because of their orientation, will show through any gaps or other inconsistencies ~~defects~~ in the top layer and thus be easily located. In addition, twists and other surface inconsistencies ~~defects~~ in the top layer will alter the

orientation of the strips in the top layer and thus correspondingly alter, i.e., decrease, the glare of the top layer at the inconsistent ~~defect~~ location.

[0082] While the high-glare/low-glare phenomenon occurs when illuminated with either visible light or infrared light, the filter 15 used in one embodiment of the system 10 substantially removes the glare caused by ambient light such that only the glare caused by the infrared light source is used to locate the inconsistencies ~~defects~~. Accordingly, the filter 15 removes the interference of ambient light as the composite structure 22 is being examined for inconsistencies ~~defects~~.

[0083] In any of the system embodiments described herein, there may be one or more cameras 12 and/or one or more light sources 14 with or without reflection elements 18 (collectively referred to as light sources, hereinafter). In addition, the one or more cameras 12 and/or the one or more light sources 14 may be moveable relative to the composite structure. The multiple cameras 12 and/or multiple light sources 14 and the moveability of the camera(s) 12 and/or the light source(s) provides system 10 flexibility in order to capture the most accurate images of the composite structure. Multiple and/or moveable light source(s) 14 permit consistent and sufficient illumination of the desired portion of the composite structure, regardless of the shape of the composite structure. Likewise, multiple and/or moveable camera(s) 12 enable capturing an accurate image of any area of the composite structure, regardless of the shape of the composite structure. As such, the multiple and/or moveable light source(s) and/or camera(s) are particularly advantageous when illuminating and capturing images of ~~and~~ curved/contoured portions of composite structures. The multiple and/or moveable light source(s) and/or camera(s) are also advantageous in illuminating and capturing images of composite strips having a width that makes it difficult to illuminate and/or capture images of the entire strip, such that the position of the light source(s) and/or camera(s) may be moved over the entire strip, and/or multiple stationary light source(s) and/or camera(s) may be positioned to cover the entire strip. Systems including moveable cameras and light sources are described in detail in previously referred to U.S. Patent Application No. 10/217,805.

[0084] As shown in FIG. 4, the system 10 can also include a marking device 62 for marking the location of inconsistencies ~~defects~~ on the composite

structure 22. The marking device 62 may be attached to the frame 28 and be triggered by a processor 66 or similar device when [[a]]an inconsistency ~~defect~~ 36 is detected. The marking device 62 may spray or otherwise deposit an amount of ink, paint or the like onto the composite structure 22 in those areas where inconsistencies ~~defects~~ 36 have ~~has~~ been detected. The markings on the composite structure 22 enables the location of the inconsistencies ~~defects~~ to be subsequently readily identified either automatically or manually.

[0085] In the particular illustrated embodiment, the marking device 62 is an inkjet marking system that sprays a small spot of compatible ink of a highly visible color onto the surface of the composite structure 22 at the inconsistency ~~defect~~ location to permit rapid access for addressing the inconsistency ~~repair and disposition~~. Alternatively, other marking methods can also be used, such as a pump-fed felt-tip marker, spring-loaded marking pen, audio or visual alerts, and the like.

[0087] FIG. 9 shows an exemplary raw or unprocessed camera image 68 illustrating a contrast between potential inconsistencies ~~defects~~, such as a pucker 75 and a twist 77, and the remaining portions of the composite structure 22 that are inconsistency ~~defect~~ free. In the illustrated embodiment, the potential inconsistencies ~~defects~~ 75 and 77 are shown as black or gray areas, while the remaining non-inconsistent ~~non-defective~~ portions of the composite structure 22 remain substantially white 72. Once the potential inconsistencies ~~defects~~ are located, the inconsistencies ~~defects~~ may be marked with the marker 62 and the linear and lateral distances to the potential inconsistencies ~~defects~~ can be determined in a manner describe above.

[0088] With further reference to FIG. 4, the processor 66 may receive the images 68 from the camera 12 or from the memory device 64 in which the images 68 have been stored. The processor 66 may then process and analyze the images to facilitate the reliable detection of inconsistencies ~~defects~~. In at least one embodiment, the processor 66 and memory device 64 are components of a conventional computer.

[0091] The user interface 76 includes a window 81 in which an image 74 of the composite structure 22 is displayed for viewing by the operator or other user.

The window 81 can also include a visual display 69 of inconsistency ~~defect~~ location by course.

[0092] Although the image 74 can be the unprocessed camera image 68 (FIG. 9), the image 74 shown in FIG. 10 can also be a processed image that has been binarized. During binarization, all shades of gray above a predetermined threshold value can be changed to white, while all gray shades below the threshold are changed to black to heighten the contrast of inconsistencies ~~defects~~ and improve the accuracy of inconsistency ~~defect~~ detection. In other embodiments, the binarization operation need not be performed but instead the raw image, rates of change of the light levels in the raw image, and/or color changes in the images can be used to identify the inconsistencies ~~defects~~.

[0093] The user interface 76 also provides user controls 78 for allowing various user inputs to the system. In the particular illustrated embodiment of FIG. 10, the user interface 76 allows adjustment to the binarization threshold. Generally, the setting of the binarization threshold involves a tradeoff between the sensitivity with which inconsistencies ~~defects~~ are detected and the resolution with which the inconsistencies ~~defects~~ are depicted. In one embodiment, the binarization threshold is set to about 128 which corresponds to the mid-point on the 8-bit digitizing range of 0 to 255. However, other binarization threshold values can be employed depending at least in part on the particular application, available lighting, camera settings, among other factors.

[0096] In addition to displaying images of the composite structure 22, the display screen 80 also includes [[a]]an inconsistency ~~defect~~ table 82 which lists the discovered inconsistencies ~~defects~~ and provides information for each inconsistency ~~defect~~ , such as location, size, and the like.

[0097] The display screen 80 can also provide information (which can be continuously updated) such as the number of inconsistencies ~~defects~~ 50, number of courses completed 52 (which may be determined by counting pressure on/off signals from the machine load cell as described above), cumulative inconsistency ~~defect~~ width 54, and length of the current inconsistency ~~defect~~ being measured 56.

[0099] The display screen can also include an indicator 85 that notifies the user when the allowable cumulative inconsistency ~~defect~~ width limit has been exceeded.

[0101] FIG. 11 illustrates an example of a complex part model 90 imported from third party software. As show in FIG. 12, a course grid overlay 92 can be constructed for the imported part model 90 using the number of courses and the direction of travel that correspond to ply orientation. The diagrammatic concepts of linear and lateral distances 19 and 21 are illustrated in FIG. 12 to show inconsistency ~~defect~~ 36 location on a surface more complex than the surface shown in FIG. 1.

[0103] FIG. 14 illustrates another embodiment in which two computer displays are employed for displaying and tracking the various inconsistency ~~defect~~ data for the imported model 90. As shown, one monitor displays the computer display 80 (previously described above in reference to FIG. 10) while the other monitor simultaneously displays a computer display 180 of the part model 90 and course grid overlay 92. The computer displays 80 and 180 can be continuously updated to show positioning and locations of inconsistencies ~~defects and flaws~~ as they are detected through the vision system interface, described above.

[0106] Accordingly, embodiments of the present disclosure ~~invention~~ provide in-process vision-based inspection systems and methods capable of accurately and efficiently determining various inconsistency ~~defect~~ characteristics such as total inconsistency ~~defect~~ count, total inconsistency ~~defect~~ width, inconsistency ~~defect~~ density-per-unit area, cumulative inconsistency ~~defect~~ width-per-unit area and/or inconsistency ~~defect~~ locations. Embodiments of the present disclosure ~~invention~~ allow composite structures to be fabricated more efficiently with fewer interruptions than conventional material placement systems which require manual inspections for and measuring of inconsistencies ~~defect~~.

[0107] Embodiments of the present disclosure ~~invention~~ permit rapid detection and measurement of the cumulative inconsistency ~~defect~~ width-per-unit area, and tracking of the inconsistency ~~defect~~ density-per-unit area. Because this inconsistency ~~defect~~ information is relatively immediately available and manual

measurement is not necessary, machine down-time can be significantly reduced resulting in reduced manufacturing costs and cycle times.

[0108] In addition, embodiments of the present disclosure ~~invention~~ allow for ready identification of those composite structures that exceed maximum allowable tolerances pertaining to density and cumulative width of inconsistencies ~~defects~~. This allows the fabrication process to be halted when maximum allowable tolerances are exceeded, thereby saving time and materials which would otherwise be lost during continued fabrication of an unacceptable composite structure.

[0110] Additionally, the various embodiments disclosed herein also enable improvements in the overall quality of the parts produced because inconsistency ~~defect~~ density and cumulative inconsistency ~~defect~~ width can be determined more uniformly and reliably with the various systems and methods of the present disclosure ~~invention~~ than with manual inspections.

[0111] While various ~~preferred~~ embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the inventive concept. The examples illustrate the present disclosure ~~invention~~ and are not intended to limit it. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.